Using Surface Pressure to Validate Tropical Cyclone Surface Wind Retrievals From SAR

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LONG-TERM GOALS

The overall goal of this research is to improve the accuracy and usefulness of wind retrievals from synthetic aperture radar (SAR) imagery of the sea surface under and near the centers of tropical cyclones (TCs). SAR provides unique high resolution (even sub-km-scale) imagery of the ocean surface roughness underneath TCs. However, the standard methods for interpreting this information in terms of surface wind were all developed using data from conditions far from the extremes of the TC environment and have proven to be lacking in this regime. We propose a new validation method using sea-level pressure fields calculated from the SAR measurements with a planetary boundary layer (PBL) model. The reason for using surface pressure measurements is that they are comparatively much more reliable than wind measurements in extreme wind conditions. Our research leverages our previous and continuing efforts in sea-level pressure (SLP) retrieval from satellite ocean vector winds, theoretical boundary layer model development, and the analysis of organized coherent structures in tropical cyclone boundary layers.

OBJECTIVES

Our objectives are to (1) Transfer our technology from ~25 km scatterometer winds to km-scale SAR winds in TC conditions; (2) Continuing development of the nonlinear boundary layer model geared towards TC conditions; and, (3) Development of the methodology for SAR winds Cal/Val and high wind retrievals through pressure observations.

APPROACH

We are actively collaborating with the members of the ONR-sponsored Impact of Typhoons on the Pacific (ITOP) SAR Working group (Hans Graber, Michael Caruso and Roland Romeiser, U. Miami; Chris Wackerman, General Dynamics; and Jochen Horstmann, NATO Underwater Research Centre)

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on a combined SAR TC analysis system that will provide a combined wind/wave/SLP data set for use during and after the ITOP field program (Summer, 2010). For this purpose, we obtained access to a collection of 162 TC SAR images obtained by the Canadian Space Agency under its Hurricane Watch program using the RadarSAT-1 satellite. These include both Atlantic hurricanes and Pacific Ocean Typhoons. Many of the Atlantic Hurricane images were obtained during or near the times of in situ observation, so some ground truth data are available. The Pacific Ocean "best-track" data are based on the Dvorak technique (Velden et al., 2006) of analyzing standard geostationary or passive microwave satellite data. Consequently, these have relatively large errors bars and include very little or no in situ data. Our group has focused on a few images obtained during the intensive observation period of the RAINEX experiment in the Atlantic Ocean and a set of western Pacific typhoons.

We have a two step approach. First we are converting our mid-latitude storm scatterometer/SLP retrieval system (Patoux et al.2003; 2008) for SAR/TC conditions and using it as a baseline for further work. Second, we are converting the simple nonlinear TC boundary layer model (Foster, 2009) for use in TC SLP retrieval. This model should perform better in the core of intense TCs than the boundary layer model used in the existing code, even though we find that it performs quite well after incorporating modifications developed under this research. Although we have developed in-house SAR wind retrieval system at APL, we use surface wind products from Wackerman and Horstmann as the primary inputs to the SLP retrieval. Once we demonstrate the ability of the modeling system to generate reasonable TC SLP fields (based on best-track or in situ data) we will use them both as Cal/Val data and to improve the near-core winds using an optimization scheme. In the latter, we seek the minimal wind vector changes to minimize the difference between the SAR-derived and measured bulk SLP gradients between multiple pairs of in situ observations such as from reconnaissance drop sondes.

Patoux has been primarily responsible for converting the existing SLP code to SAR TC images and performing the analyses. Foster has been converting the new nonlinear PBL code to SLP retrieval and developing the optimization techniques for improving the surface winds. Foster has also focused on validating the SLP retrievals against available data.

WORK COMPLETED

We have nearly completed coupling the existing SLP code to the optimization methodology and performed some preliminary tests on imagery from hurricane Katrina. Since that time, we have uncovered and implemented a significant improvement in the standard SLP model as applied to SAR/TC, but have not yet implemented it into the coupled optimization scheme. We have surveyed a set of nine West Pacific ocean SAR images using winds from General Dynamics. These included some with serious image flaws affecting the wind retrievals. Even so, our technique is capable of using the best information within an image somewhat independently of the lower quality regions within the same image. Initial tests with the new (Foster, 2009) PBL model have indicated that, although it did well in predicting the minimum surface pressure, significant speed-up will be necessary in order for it to serve in near-real-time for SLP retrieval during ITOP. The experiments performed thus far have provided some clues as to how best to make the code more efficient. Fortunately, the existing SLP code (including the modifications developed as part of the West Pacific Ocean analysis) shows great promise for meeting our short-term goals and for support during ITOP.

RESULTS

Figure 1 shows a summary of the SAR-derived minimum SLP compared to the best track estimates from the Joint Typhoon Warning Center (JTWC) and the Japanese Meteorological Agency (JMA). Both JTWC and JMA use the Dvorak method, although the different agencies include different modifications of the basic technique. In summary, the Dvorak technique uses a variety of conventional satellite data to estimate a current intensity (CI) number for the TC. The CI number are only estimated to whole- or half-integer values, so the best track error bars for the estimated minimum SLP can be quite large. For example, the minimum SLP for CI = 5.5, 6, 6.5 western Pacific typhoons are 941, 927, 914 mb respectively. Hence, we estimate that the central pressure for a CI = 6 typhoon is 927 (+7, -6.5) mb. For comparison with the SAR imagery, we interpolated to the SAR overpass times. The SAR-derived minimum SLP track the best track values reasonably well. Based on the working group analysis of wind retrieval methods, we expect that the wind retrievals will be improved prior to the ITOP field phase and the corresponding SLP retrievals will consequently be improved.

Figures 2, 3 and 4 show the SAR-derived SLP superposed on the surface winds for Usagi Yagi and Kajiki respectively. These are all descending passes. RadarSAT-1 looks to the right (facing downwards) of the satellite, so the high incident angles are towards the eastern edge of these images. High wind retrievals in the high incident angles are problematic. The winds are derived on 1-km square pixels (wind vectors are only plotted every 20 km). Usagi is an example of a very good wind retrieval (the eye is in the low incident angles) and the retrieved SLP is correspondingly good. In the case of Yagi, the eye is closer to the low incident angle regime and we see probable evidence of erroneously low winds to the north east and southwest of the eye, which may account for the exagerated oval shape of the SLP fields. We will need to compare with ancillary satellite imagery to see if the elongated shape is correct. However, the SLP method, if it is given a sector of reasonably good winds, can still estimate the central pressure reasonably well. Kajiki provides the most difficult test of this. The wind field has a strong “hourglassing” of the wind speeds, which is an indicator of problems with the application of the existing model functions to the SAR backscatter. Even so, the wind field in the southern part of the image provides enough information to estimate the central pressure.

It is important to note that the SAR-derived SLP fields are sensitive to the accuracy of the SAR-derived surface wind field. Hence, they serve as an import quality and “sanity” check on the SAR-derived winds. This will be important during the field phase of ITOP. We are also working with both Wackerman and Horstmann as they improve their wind algorithms and data products in support of ITOP. These results indicte that our overall research goal of using the surface pressure data to improve the surface wind retrievals is likely to produce good results. Furthermore, we can use the SAR-derived SLP fields to make an SLP-smoothed estimate of the surface wind field, from which a second estimate of the range of gale force and hurricane force winds can be made.

IMPACT/APPLICATIONS

In the short run, we will be able to provide useful feedback to the SAR surface wind model developers that will improve the surface wind fields produced for ITOP. In the longer run, we will be able to use the surface wind fields as a sensitive means for improving the geophysical model functions used to derive surface winds from SAR images.

RELATED PROJECTS

Foster is also involved with the Tropical Cyclone Structure, 2008 (TCS-08) experiment (ONR Marine Meteorology: N00014-08-1-0247). The task is to analyze Doppler wind lidar profiles of vector winds obtained in the boundary layers of developing and mature western Pacific typhoons. There is significant overlap in terms of understanding typhoon boundary layer structure and these data will be used to better characterize certain parameters in the Foster (2009) hurricane boundary layer model. Both PIs are currently co-PIs on the NASA Ocean Vector Winds Science Team. The basic SLP retrieval methods and the Foster (2009) model were developed under that grant (and predecessors).

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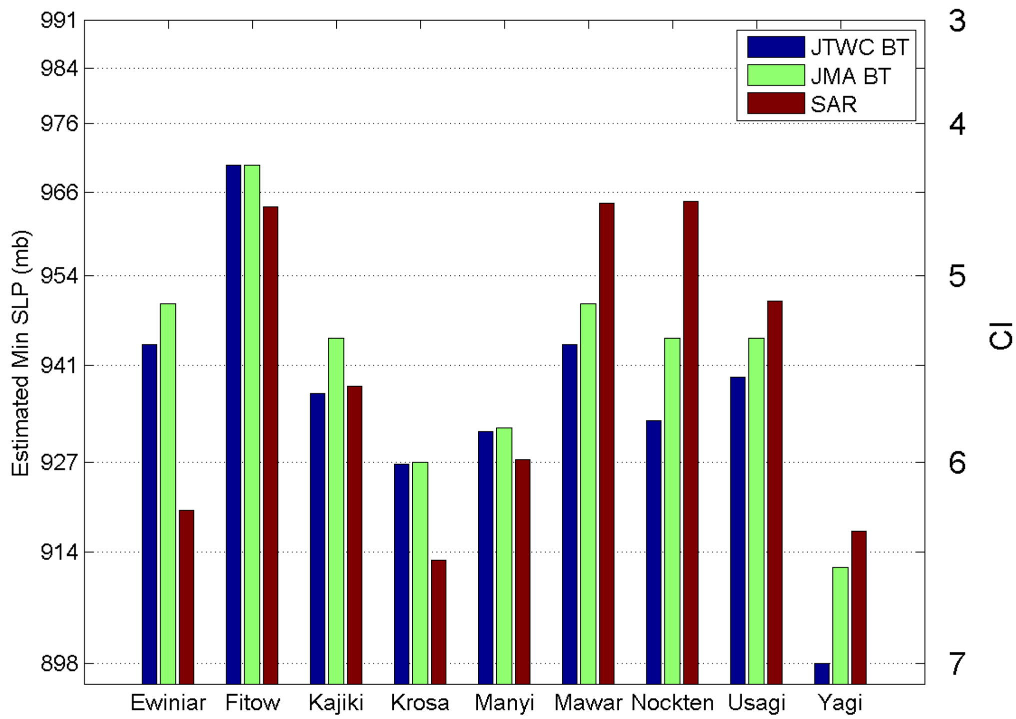

Figure 1: Comparison of SAR-derived minimum SLP (red) with best-track minimum SLP estimated using the Dvorak method at JTWC (blue) and JMA (green). Right y-axis shows the CI numbers corresponding to the marked values of minimum SLP. Best track minimum SLP were linearly interpolated to the SAR overpass time.

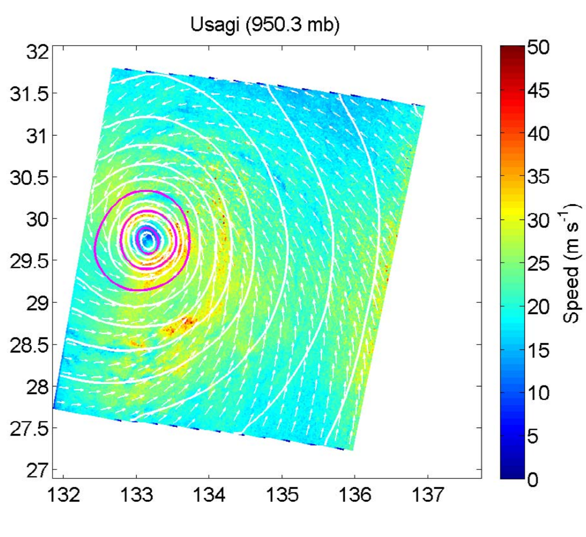

Figure 2: Usagi winds and SLP.

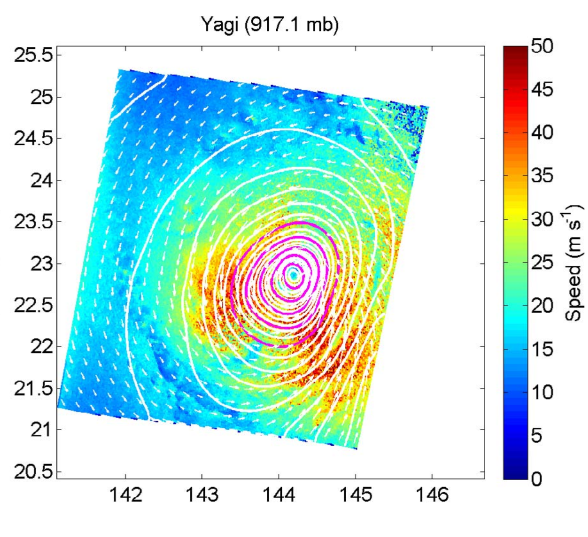

Figure 3: Yagi winds and SLP

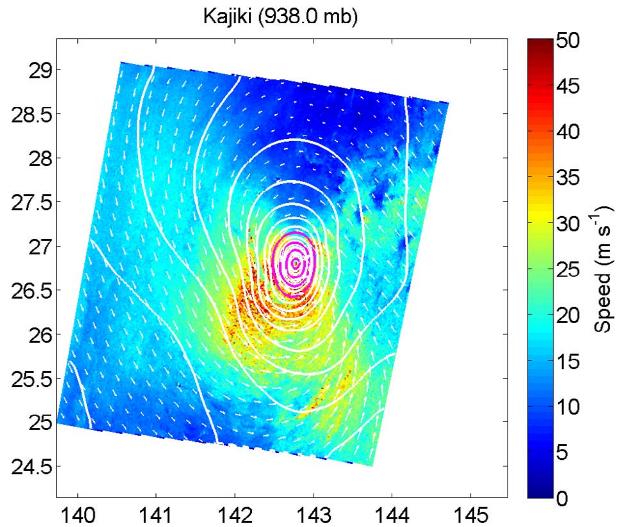

Figure 4: Kajiki winds and SLP.